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It is in the field of physiology more than anywhere else, perhaps, that the worker must humble himself before the immensity of the problems before him; that he must realize how fragmentary is the most advanced knowledge of this subject. The foundation stone of physiology is chemistry, and consequently its advance must go hand in hand with the advance of that science; but there is also, it must be admitted, the element of empiricism, which is an unfortunate necessity in any branch of learning where any considerable mass of facts are not yet correlated. The greatest advances are made in the direction of resolving this empirical information into more compact and definite form, a task only possible by the accumulation and correlation of great masses of data in connection with the more definite information afforded by chemistry or physics and more particularly modern physical chemistry. It is plain, then, that we can never go ahead of the data afforded by these sciences, but must always follow somewhat behind them. It must not be supposed, however, that physiology is in a nebulous condition, despite the fact that we are but on the margin of the unknown. Distinct and creditable advances have been made since the days when the knowledge of plant morphology and the chemistry of Lavoisier made possible any reasonably satisfactory explanation of the functions of plant organs. The establishment of a proper understanding of how the plant obtains its food has been a matter of the utmost importance, both from the development of theoretical physiology, and from the standpoint of practical use. We

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know not only the definite chemical elements which are essential for plant life, but we know also the quantity and form in which they are most favorable for plant growth. Having established this, it is possible to understand the rôle of plants in the general economy of the world, and how their manner of life, in a broad sense, supplements that of animals. There is also pretty definite information as to the physical phenomena connected with the absorption of the raw food materials which the plant afterwards elaborates, information which is largely due to the classic researches of Pfeffer, whose work, it may be remarked, also afforded van't Hoff valuable data for his contributions to the establishment of the modern physical chemistry. Application of the laws of diffusion and of osmosis, as shown by Pfeffer, enables us to understand why a plant may absorb more of one mineral salt than of another, though both be presented to it in solutions of equal concentration; why it cannot absorb some substances at all, while on the other hand it cannot avoid absorbing certain substances, even though they be violent poison and kill the protoplasm of the absorbing cell at once. We understand also a good deal of the mechanism of the production from simple inorganic substances of the first organic food by the green plant, the first organic food of the whole organic world. While, as will be shown later, the precise details of this process are not fully understood, the general facts are a matter of almost common information, so well known that I hesitate to speak of it here, though to sum up the matter in a few words it may be said that this process of photosynthetic activity of green plants is carried on by the living cells in the presence of sunlight, through the agency of the green coloring matter — chlorophyll — which is present in the leaves, and that the chemical reaction involved results in the union of the carbon dioxide absorbed from the air, with water absorbed from the soil, to form the first simple carbohydrate that is to be detected in easily recognizable form as starch. The fact that this process takes place does not interfere with the operation of another one, namely, the absorption of oxygen with the giving forth of carbon dioxide, that is concerned in the mechanism of respiration. Respiration as a means of releasing the stored energy in available form for the constructive work of the organism is as necessary in plants as it is in animals. These four fundamental questions, namely, the inorganic substances required by plants, the manner of their absorption, the manufacture of the first organic food, and the nature of respiration are perhaps the most important physiological facts, in the field of nutrition at least, which have been definitly established, and from any point of view their importance is a far reaching one.

In the other great field of physiological research, the study of the mechanism of growth and change of form, much information, made possible by the proper understanding of the cellular character of all living organisms, has established many facts as to the relation of plants to the great physical forces which govern the conditions, the rate and the direction of their growth. This is the study of the dynamics of plants, of when and how the energy released by the nutritive functions is applied to the upbuilding of new tissue and the movement of plant organs. Besides the questions concerned in the influence of diffusely exerted external factors, there are also the effects produced by these same forces when the stimulus is unequal or one-sided. The latter conditions result in characteristic growth curvatures or tropisms, which continue until the plant organ by its own action is brought once more into a state of equilibrium with the external forces. In short, the various plant organs are attuned to the normal conditions of equilibrium under which they grow, and have the ability to perceive and, to a limited extent, to transmit the impulses resulting from a disturbance of that equilibrium. This brings us to the question of the sense perception of plants, manifested in a somewhat bizarre fashion in the sensitive plant, but we should go very slowly in the direction of interpreting this perception in the same terms that we do that of higher animals. It is not for an instant to be supposed that plants have any nervous system such as is characteristic of the higher animal forms. While plants can and do respond to differences in light intensity less than that which the human eye can perceive, it is gratuitous to suppose that there is anything analogous in the two processes. The possibility of any reasoning action or instinct on the part of plants is a question that the plant physiologist does not seriously entertain.

In selecting for discussion present-day problems which may be considered fundamental, one is embarrassed by the wealth of material and therefore but one more or less connected series of topics which leads up to the modern mechanistic conception of life processes has been chosen. In doing so it has been necessary to ignore equally important questions which, though developed from no less a mechanistic standpoint, are more scattered.

In referring to the assimilation of carbon dioxide by green plants and the production of organic food thereby, it was necessary to admit that the details of the process are not satisfactorily known. It is evident, however, that the starch, which is the first substance that we readily recognize, is not the first substance which is formed. Modern research points more and more to the conclusion that it is the simplest of carbohydrates that is produced, — a substance known as formaldehyde. But what is especially interesting is that it seems not impossible that this primal reaction may not after all be a function of the living protoplasm, but a chemical reaction that can be carried on outside the cell through the agency of chlorophyll. It is in the further elaboration of this first substance formed that the living protoplasm is apparently necessary. At any rate we know that the energy demanded for the process must be afforded by the particular rays of sunlight which the chlorophyll absorbs.

In this photosynthetic activity of the green plant the carbohydrate supply of the world has been accounted for, but there is an equally important question not concerned in this process, namely, the source of nitrogen. Nitrogen is of course an essential element for the construction of protoplasm. As is well known most plants can utilize it in simple combination with oxygen in the form of a nitrate, a sharp contrast, by the way, to the typical animal which requires it offered as an organic compound. It is also known that the same plants cannot assimilate the free nitrogen of the atmosphere, and further, in the processes of decay, free nitrogen is liberated by the breaking down of the nitrogen compounds in dead organic matter. The logical conclusion of these momentous facts is that soon all the world's supply of combined nitrogen would be exhausted — neglecting the relatively small replenishment induced by cosmic forces — so that green plants and consequently animals, would not have the wherewithal to live, unless there were some organisms which could avail themselves directly of this inert gas. Now there are plant organisms which have the ability to assimilate the uncombined nitrogen of the air : certain bacterial forms, and it also appears some somewhat higher plants. But the operations that lead to this result are by no means satisfactorily explained, and the whole topic is one of live interest both from a theoretical as well as a practical standpoint. It should be added that from the latter point of view, a process by which a combination of nitrogen with other elements in a form that is acceptable to green plants has been devised, and bids fair to become of great importance, for combined nitrogen is the great need of the organic world.

The processes of nitrification naturally lead us to the question of the elaboration of nitrogen compounds within the cell, of the final construction of proteid material that is the actual food of the protoplasm ; but here we are much in the dark, partly because we have so little real information as to the chemical structure of the more complicated nitrogenous substances. The explanations now given as to how this elaboration takes place are largely hypothetical and must be regarded as quite unsatisfactory.

A step further from the proteid food is the question of living protoplasm itself, and one of the most interesting problems connected with this is the nature and functions of the enzymes, — the ferments and digestive secretions of living cells. Many of the newer theories as to the nature of living protoplasm hark back to investigations regarding enzymes, indeed some extremists advance the opinion that the activities of the live protoplast are in themselves but the result of the interaction of substances enzymatic in their nature. There is no doubt of the power of the appropriate enzymes when present even in infinitesimal amount to cause enormous molecular changes in the substances on which they act, but it is necessary to exercise extreme caution before accepting generalizations along this line, no matter how brilliant. The amount of empirical information in this field is already becoming unwieldy, and nowhere else is the necessity of unifying principles so plainly shown. Here it is that more definite chemical knowledge may in one stroke clear up the whole situation.

If it is not possible to ascertain the chemical structure of a single enzyme, how much more difficult then must it be to determine that of the living protoplasm? It goes without saying, that if we try to analyze the living protoplasm, in the ordinary chemical sense, we kill it. This being the case, the student who is trying to penetrate these difficult problems must have recourse to other modes of attack. Therefore does he experiment with the effect of agents which do not kill but merely stimulate the organism or partially inhibit its functions and, by studying the nature and products of the reactions produced, obtain in an indirect manner clues to the real nature of life processes. The fascination of these plunges into the unknown is perhaps hardly comprehensible to those who are not engaged in the work, but all must admit the importance of the end they have in view, namely to penetrate a little further into the mystery of life. The advance in all these fields is of necessity along the line of the mechanistic conception of vital manifestations, that is, the reference of them to chemical and physical laws. To appeal to a "Vital Force" is, as my predecessors in these lectures have said, to appeal to an empty name, a mere "question-begging epithet." It is obvious that if we are to make any progress at all, we must admit of the possibility of some solution that our senses can perceive, even though we are perfectly willing to admit that the final answer may never be reached. The reference of vital phenonema to a vague "Vital Force" would mean the extinction of inquiry by robbing the investigator of any sense of responsibility for adequate explanations of the results of his researches.

(*To be continued.*)